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ULTRASONIC TEMPERATURE MEASURING DEVICE

by

E. H. Carnevale, L. C. Lynnworth, and S. L. Klaidman

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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First Quarterly Progress Report

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ABSTRACT

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During the first quarter, work proceeded as scheduled on room and elevated temperature preliminary ultrasonic measurements, and capsule design, construction and testing (nonradiation tests only). The analysis and experiments so far reveal no difficulties not originally anticipated. Radiation effects, including transmutations, are expected to be insignificantly small. Ultrasonic transmission tests indicate that "lead-in" wires at least 40 ft. long can be used between the transducer coils and the sensor element. By slightly modifying the transducers and the pulsing unit, 1 in. sensors should be usable over the entire temperature range, together with an expected thermometry accuracy of about 1%.

In preparation for the high temperature irradiation experiments, capsules have been designed, incorporating both gamma and electrical heating. These designs provide a high temperature soak due to gamma heating, plus electrical heating to raise temperatures to the maximum levels required.

Author

I. SUMMARY

During the first quarter, work proceeded as scheduled on Phases I and III.

Phase I consists of room temperature preliminary ultrasonic measurements, and capsule design, construction and testing (non-radiation tests only).

Phase III extends the room temperature ultrasonic measurements to elevated temperature, i.e., up to 5000°R.

The analysis and experiments so far reveal no difficulties not originally anticipated. Radiation effects, including transmutations, are expected to be insignificantly small. Ultrasonic transmission tests indicate that "lead-in" wires at least 40 ft. long can be used between the transducer coils and the sensor element. Using a 6 ft. long Mo wire, a kink was resolved 1-1/2 in. from the end at room temperature. This time resolution corresponds to a 1 in. Mo sensor length above about 4000°R. Furthermore, minor modifications of the transducers and the Wien bridge in the pulsing unit should permit the use of a 1 in. sensor length over the entire temperature range, together with an expected thermometry accuracy of about 1%.

In preparation for the high temperature irradiation experiments, capsules have been designed, incorporating both gamma and electrical heating. These designs provide a high temperature soak due to gamma heating, plus additional controlled electrical heat to raise temperature to the maximum levels required.

Thus, based on the first quarter's work, it appears that the basic contract goals are reasonable, and requirements are being met on schedule.

Details on the progress in Phases I and III are given in the body of this report.

II. PROGRESS ON PHASES I AND III

A. Introduction

Determination of temperature from sound velocity measurements was suggested nearly 100 years ago by Professor Mayer.[1] The temperature dependence of the sound velocity may be measured in a gas, liquid or solid. Although the method is quite simple in principle, it has not been applied to high temperatures except in a few instances.[2]

Most ultrasonic thermometry work in solid wires to date has been done in England in connection with reactor core temperature determination in the Dragon Project. Professor J. F. W. Bell,[3] in particular, developed the basic notched wire system described below. Working with Jaques of the Atomic Energy Establishment, in Winfrith, England, Thorne,[4] Hub[5] et al applied Bell's thin wire system to the measurement of temperature. These investigators have tested many wires at elevated temperatures, including rhenium to 4100°R, and molybdenum to its melting point, 5200°R, but radiation effects have not been determined experimentally. Accordingly, one of the principal objects of this quarter's work was to prepare for radiation tests of various wires at elevated temperatures.

B. Method

The ultrasonic temperature sensor is shown schematically in figure 1. A transmitting coil launches a pulse in the magnetostrictive tube. Part of the pulse is reflected from the kink, and part is reflected from the end of the wire. The time T between the two echoes can be measured with great precision (0.1%). If the sensor length is designated s, then the velocity of sound in the sensor is given by:

$$v = 2\,s/T.$$

Details of the measurement are given by Bell.[3] Bell and his co-workers found that to achieve highest accuracy in the measurement of T it is necessary to transmit alternate pairs of pulses. Spacing between pulses is $T + \delta$ in the first pair, and $T - \delta$ in the second pair. The average time interval T between pulses is adjusted until the end echo from the first pulse "coincides" with the kink echo from the second pulse. When displayed on an oscilloscope, "coincidence" is most accurately indicated by tuning the oscillator until kink plus end echoes from alternate pulse pairs are adjusted to equal amplitude.

The temperature dependence of the sound velocity in the sensor is determined experimentally. As an example, figure 2 shows the measured temperature dependence of sound velocity in polycrystalline rhenium up to 4100°R (M. Pt. 6200°R).[6] Curves for polycrystalline molybdenum, tantalum and tungsten are also shown, calculated from Armstrong and Brown's dynamic modulus measurements,[7] using the relation $v = \sqrt{E/\rho}$ where E = Young's modulus and ρ = density.

To achieve remote, automatic temperature measurement, the electronic portion of figure 1 may be modified to include an analog output proportional to temperature. The modified, automatic system will be developed later in this contract. To control core temperature, the thermometer analog output would be used in a servo loop to adjust control rods.

Calibration of the thin wire sensors up to 5000°R will be accomplished in the oven shown in figure 3. This oven, capable of 7000°R, has been described elsewhere.[8] Temperature will be measured independently by pyrometer, thermocouple and/or ultrasonic[2] means. (Ultrasonic means include not only the thin wire sensor, but also a sound velocity measurement across a helium gas path in the hot zone.)

C. Ultrasonic Test Results

1. "Lead-in Wire." Ultrasonic measurements on various wires up to 40 ft. long indicate that "lead-in" wires of this length present no attenuation problem. However, it is important that any supports for the lead-in neither couple out too much acoustic energy from the wire, nor introduce reflections at points of contact. Since most of the lead-in will generally not be at greatly elevated temperatures, there exists a relatively wide choice of materials. (The use of composite or two-section insulating materials and sheaths has recently been applied to thermocouple insulators and sheaths for use up to 5000°R.)

In laboratory tests, or in nonradiation applications where elastomers are allowable, rubber O-rings are suitable supports. Experimentally, we found that a Mo wire could be supported on O-rings along the axis of 1/4 in. copper tubing, without any reflections at the supports. This arrangement is somewhat analogous to using insulating beads in coaxial electrical transmission cables. The O-ring technique will be used in the high temperatures tests (figure 3), to permit convenient leakproof piercing of the oven shell at the top.

Near high temperature regions, supports made of graphite appear suitable. Several granulated or powdered refractories, particularly magnesia, could also be used. Graphite and magnesia have relatively low acoustic impedances compared to dense metals. Supports of these nonmetallic materials would have minimum acoustic interaction with metal wires of Mo, Ta, Rh or W, or their alloys.

Regarding bends in the lead-in, it was found that with a 90^{o} bend of 1 in. radius of curvature located about 5 ft. from the end, echoes originating 1 in. from the end could be resolved on single pulse mode.

2. Sensor Length. The pulsing unit and transducers used in the Dragon Project laboratory experiments generally utilized a sensor length of 5 to 10 inches. One of our present objectives is to achieve a sensor length of 1 in. In tests on a 1 mm, 6 ft. long Mo wire, we found that a kink 1-1/2 in. from the end could be resolved at room temperature, operating in double pulse mode, without modifying transducers or pulse or detection circuitry. However, to achieve a practical sensor length of 1 in., it appears that shorter transducer coils, smaller diameter, thinner walled nickel tubing, and minor changes in the pulsing unit, would offer improvement. Increase in power output should also improve resolution.

D. Capsule Designs

To study effects of radiation on the proposed thermometry sensor as a function of temperature, it will be necessary to test a number of wires. The experiments are most easily conducted by using several different types of capsules.

1. Unheated, Unmonitored Capsule. The simplest capsule would merely contain many wire samples. These wires would be irradiated at room temperature. Sound velocity and attenuation would be measured before and after irradiation. To obtain the required range of exposures, capsule position in the reactor, and exposure duration, would be chosen appropriate to other experimental conditions, especially those conditions imposed by neighboring capsules.

2. Unheated, Acoustically Monitored Capsule. A second capsule would permit wire samples to be acoustically monitored continually during irradiation, but would not provide any heating.

3. <u>Heated, Monitored Capsule.</u> The third capsule would permit acoustic monitoring of wire samples, and in addition, would permit temperature to be controlled up to 5000°R. It is planned to use gamma heating, suggested by M. O. Dustin of NASA-Lewis, to achieve an elevated temperature of several thousand °R, and to supplement this with electrical heating which may be required for further annealing at temperatures up to 5000°R.

4. <u>Gamma Plus Electrical Heating.</u> The reasons for choosing gamma plus electrical heating over either heating type alone are as follows. If gamma heating were used alone, it would be difficult to control or adjust the temperature distribution and maximum temperature. Assuming thoria or urania gamma heaters, temperature increase of about 2000°R can be expected at the axis, for an outside wall temperature of 500°R. Thus, these heaters could not achieve 5000°R. Also one could not easily determine the minimum temperature at which adequate annealing occurs. To study different wires, different gamma heated capsule constructions would be required, probably one per wire type. Temperatures can be lowered to some degree by flowing cold He through the capsule. Possibly, higher temperatures could be attained with composite gamma heaters, for example, a tungsten center, surrounded by a dense, insulating ceramic.

On the other extreme, if electrical heating were used alone, the entire heating burden falls on one, or possibly two or three, electrical elements. Should a heater open up, the remaining heaters might not be able to sustain the required temperatures.

By taking advantage of the high gamma flux available, one can establish some intermediate temperature, several thousand °R, for example, and then raise this temperature as required by energizing the electrical heater(s). Thus, by using both gamma and electrical heating, a more reliable, more easily regulated high temperature capsule is achieved. (Independently, Babcock and Wilcox have scheduled large scale tests up to ~1200°R using gamma plus electrical heating, and flowing gas for a coolant. Results of the tests may influence some of the design details of the capsules to be described below.)

All capsules, both heated and unheated types, would be instrumented with thermocouples. The monitored capsules may be contained in adjacent sections of a long tube.

Of the three capsules, the heated, acoustically monitored capsule should provide the most important data on elevated temperature annealing of radiation-induced damage.

5. Coiled Foil with Insulated Turns. One design of heated capsule is shown schematically in figure 4. A coiled refractory metal foil serves as a dual purpose heater (i.e., gamma plus electrical heater). Foil thickness is about 0.001 in. Between turns, a refractory insulator in the form of a powder is uniformly dispersed, and this insulator also serves more than one purpose. First, it reduces the thermal conductivity in the radial direction. Second, it electrically insulates the turns from one another, so that a hot resistance, of the order of ten ohms, can be developed between the innermost and outermost layers of the coiled heater. This resistance is easily heated by using a Variac, and current levels of 10 to 20 amps. Third, the refractory insulator is also a gamma heater.

a. Power and Temperature Distribution. The current path through the coil is seen to spiral through the entire length of the coil. The power generated in any turn is proportional to the resistance of that turn. Since the resistivity of metals generally increases nearly linearly with temperature, electric power dissipation will follow the temperature distribution very closely.

In a given volume, to achieve more gamma heating, one chooses a greater proportion of dense metal, and a lesser portion of insulator. (In the present case, the outside diameter of the capsule is limited to ~1-3/4 in.).

b. Earlier Use of Coiled Foil. The use of coiled refractory metal for thermal radiation shielding has been demonstrated at NASA-Lewis by Ebihara and Kaczmarek.[9] Ebihara and Kaczmarek typically use about 3 turns of 0.001 in. thick tungsten foil, with turns separated by "tungsten wool," as a thermal radiation shield around a thicker tungsten cup susceptor (2 in. dia. x 3 in. high x ≈ 0.050 in. thick) inductively heated at 10 kc. In this work susceptor temperatures of 5000 to 6000°R are achieved routinely.

c. Metal/Insulation Proportions. To optimize the figure 4 capsule design with respect to coil and insulation proportions, calculations and experiments will be performed for several cases. In one limiting case, for example, about 100 ft. of 0.001 in. foil would be heated, and the insulating particles would separate the turns by about 0.002 in. Spacing is limited by the availability of fine mesh refractory powder. It appears that thoria, for example, is available in particles no finer than 0.0017 in. diameter.

d. Simulation of Gamma Heating. To electrically simulate gamma heating, one would prefer to heat uniformly throughout the heater. However, any convenient electrical heating, either dc or ac (60 cycle or higher frequency inductive heating, ~500 kc to 1 mc), leads to more concentrated I^2R heating near the center of the capsule heater, where temperatures and resistivity are highest. One can partly offset this tendency, if required, by insulating only between every second or third turn (or nth turn, in general) in the hotter portions. Thus, the increased cross sectional area of shunted turns would offset the increased resistivity at elevated temperature.

The design shown in figure 4 is expected to yield good axial temperature uniformity, since heat loss is essentially one-dimensional (radial), and gamma and electrical heating of the foil should be nearly uniform axially.

e. Pre-Radiation Testing of Capsule. Prior to radiation tests, heat transfer and temperature distribution in the heated capsule will be studied. Optical and thermocouple temperature readings will be obtained for various electrical power levels in the range ~1 to ~5 kw. Dc or 60 cycle ac heating will be used. Rf heating also could have been used in these pre-radiation tests, but this approach was abandoned because it would be difficult to monitor the electrical power dissipated in the heater. (However, in other applications the coiled, insulated foil might provide an interesting rf susceptor, at frequencies where the skin depth is comparable to foil thickness.)

Our early tests on winding 0.001 in. stainless steel skin showed that mating spring pins can be used to capture and thus support the foil at its innermost and outermost edges. These pins provide convenient electrical terminals, adequate for the anticipated current of 10 to 20 amps. To check the construction and assembly details, a longer coiled foil heater of 0.001 in. stainless shim will be wound, and tested electrically and mechanically for defects. A refractory foil heater will be wound next, and if found satisfactory, this heater will be installed in the irradiation test capsule.

6. Moderately Heated Electrical Element. Babcock and Wilcox, Lynchburg, Va., suggested another approach to a gamma

heated plus electrically heated capsule. In this design, the gamma heated portion is surrounded by a concentric electrically heated tube. This tube need be heated only to a moderately elevated temperature, according to the Babcock and Wilcox suggestion, to substantially reduce radial heat loss out of the gamma heated portion. If the gamma portion is well insulated, the hottest parts of the capsule could theoretically reach temperatures well above the temperature of the electrically heated tube (for example, temperature rise of $\sim 2000^{\circ}R$ for thoria or urania tubular gamma heater). This design, however, would exhibit low thermal diffusivity, and so the hot zone temperature could not be changed quickly. Nevertheless, one experiment is planned, figure 5, in which we will measure the electrical power P_1 required to maintain particular hot zone temperatures T_1, as a function of nichrome temperature T_2. P_1 would be dissipated in a coiled Mo wire. P_1 is intended to simulate the power that would have to be generated by gamma ray absorption in the insulation in the absence of the Mo wire. Departing slightly from the Babcock and Wilcox suggestion, two electrical elements could be used. For example, the nichrome tube and the Mo coil could be connected in parallel. Nichrome's resistivity increases very slightly with temperature, $\sim 7\%$ on heating from 500 to $2500^{\circ}R$, whereas the resistivity of Mo increases by more than an order of magnitude (5.7 to 80 $\mu\Omega$-cm; see DMIC Rpt. 190, p. A-4) on heating from 500 to $5000^{\circ}R$. Through suitable proportioning of the two heaters, one can arrange the elements so that at low temperatures Mo would draw most of the power. As temperature increased, Mo would dissipate a smaller fraction of the total electrical power. Thus, paradoxically, Mo could govern the lower temperatures, and nichrome would govern the higher temperatures. This arrangement affords faster heating and better control of the hot zone temperature, than the use of the nichrome tube as the only electrical heater.

III. FUTURE WORK

During the next quarter, work will continue on Phases I and III, and Phase II will be initiated, as scheduled.

Radiation capsules will be constructed, and tested electrically and mechanically. The designs will also be reviewed for reactor safety requirements.

Ultrasonic measurements will be extended to elevated temperatures. Hysteresis effects due to annealing cycles, and effects of carbiding, recrystallizations and grain growth will be determined. Single and polycrystalline sensor materials will also be compared.

IV. REFERENCES

1. A. M. Mayer, Phil. Mag. 45, 18 (1873).

2. Parametrics, Inc., has developed sonic and ultrasonic thermometry in gases and solids over several years under contracts NASw-549, NAS3-5201, Nonr-3918(00) and Nonr-3386(00). Relevant publications and presentations include E. H. Carnevale, H. L. Poss and J. M. Yos, "Ultrasonic Temperature Determination in a Plasma," in Temperature - Its Measurement and Control in Science and Industry (Reinhold Publishing Corp., New York, Vol. 3, Part 2, p. 959, 1962); E. H. Carnevale, G. S. Larson and L. C. Lynnworth, Ultrasonic Determination of Temperature and Transport Properties in a High-Temperature Gas, presented at 66th Meeting, Acoust. Soc. Amer., Univ. of Mich., Ann Arbor, Mich. (Nov. 6, 1963); J. Acoust. Soc. Amer., 35 (11) 1883 (Nov. 1963); 36 (9) 1678-1684 (Sept. 1964); 36 (10) 1999 (Oct. 1964); G. S. Larson, R. N. Lawson and L. C. Lynnworth, Upper Atmospheric Sonic Thermometry, presented at ISA-AMS Joint Session, Atmospheric Temperature Measurement, 19th Annual ISA Conference, New York City (Oct. 12, 1964) to be published in ISA Trans.; E. H. Carnevale, L. C. Lynnworth and G. S. Larson, Ultrasonic Thermometry of High Temperature Gases in a Nuclear Environment, presented at 1964 IEEE Symposium on Sonics and Ultrasonics, Santa Monica, Calif. (Oct. 14-16, 1964), NASA CR-54339 (Feb. 1, 1965); Iron Age 195 (17) 75-77 (Apr. 29, 1965). Also see H. H. Plumb and G. Cataland, Science 150, 155-161 (Oct. 8, 1965); J. Apfel, Rev. Sci. Instr. 33 (4) 428-430 (Apr. 1962).

3. J. F. W. Bell, Phil. Mag. (8) 2, 1113-1120 (1957); Dragon Project Rpts. (Oct. 1960); Proc. 4th Int. Cong Acoust., J52, Copenhagen, (1962).

4. E. A. Thorne, Proc. 4th Int. Cong. Acoust., P23, Copenhagen, (1962); Temperature Measurement by Sonic Methods, presented at Inst. of Phys. and the Phys. Soc., and the Soc. Instr. Tech. Conf. on the Measurement of High Temperature, London (11-13 May 1964).

5. D. R. Hub, Proc. 4th Int. Cong. Acoust., J51, Copenhagen, (1962).

6. E. A. Thorne, private communication (Sept. 1963).

REFERENCES (cont'd)

7. P. E. Armstrong and H. L. Brown, Trans. Met. Soc. of AIME, 230, 962-966 (Aug. 1964).

8. C. D. Pears, A Progress Report on a 6500°F Furnace for Thermophysical Property Studies, presented at the Thermal Cond. Conf. Gatlinburg, Tenn., (Oct. 1963); C. D. Pears, F. J. Digesu and J. D. Woodward, The True Stress-Strain Properties of Brittle Materials to Very High Temperatures, Final Rept. to AEC, 1963-1964, under contract No. AT-(40-1) - 2964 (Oct. 30, 1964); Research/Development 15 (8), cover, 9 (Aug. 1964); E. H. Carnevale, L. C. Lynnworth and G. S. Larson, NASA CR-54339 (Feb. 1965).

9. B. T. Ebihara, NASA Tech. Brief 65-10188 (June 1965), and R. Kaczmarek, private communications (Oct. 14, 1965).

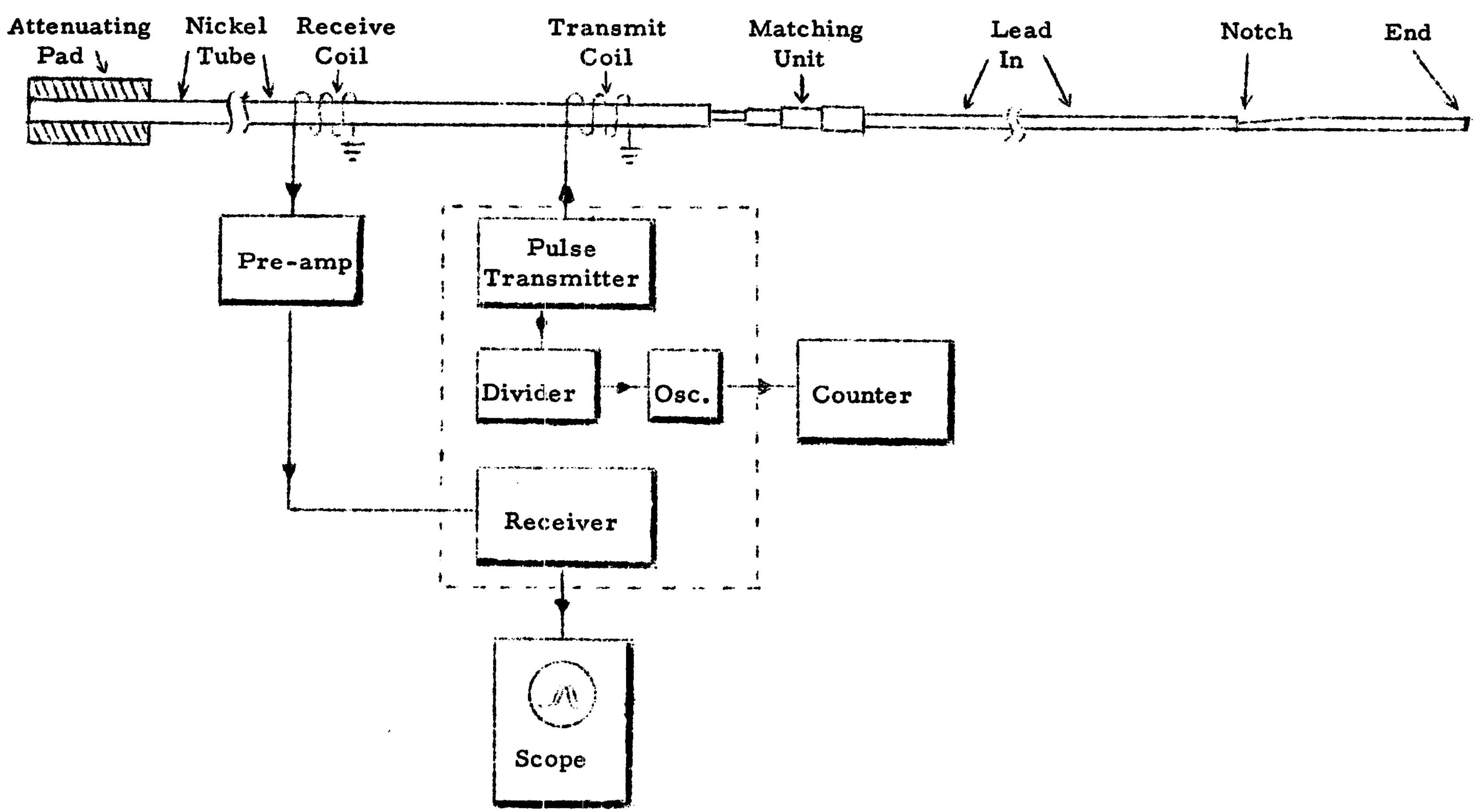

Figure 1. SCHEMATIC OF THIN WIRE ULTRASONIC THERMOMETER.

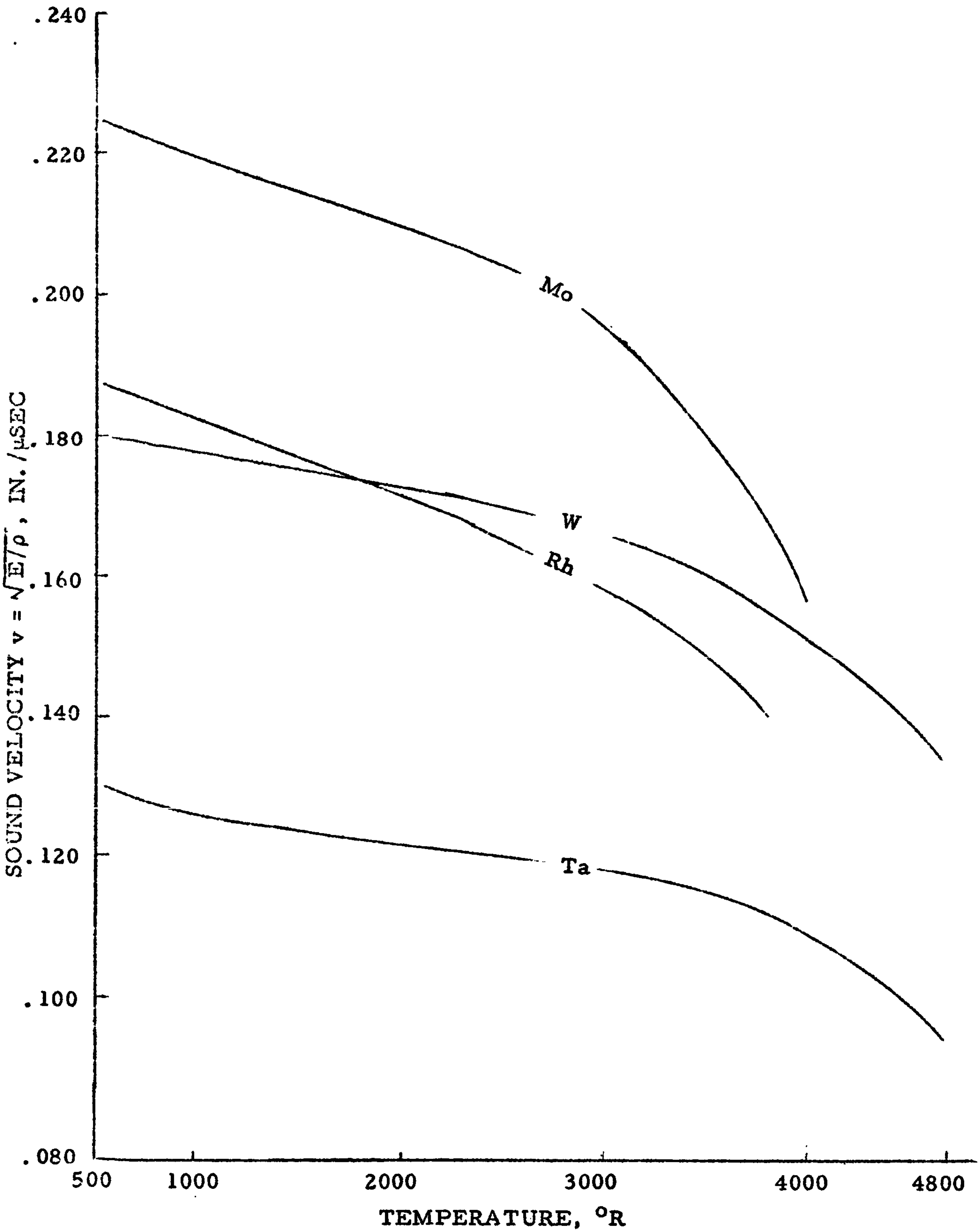

Figure 2. SOUND VELOCITY IN THIN WIRES VS. TEMPERATURE. (Rhenium data from E. A. Thorne, priv. commun., Sept. 1963; W, Mo and Ta velocities calculated from dynamic modulus data of Armstrong and Brown[7]).

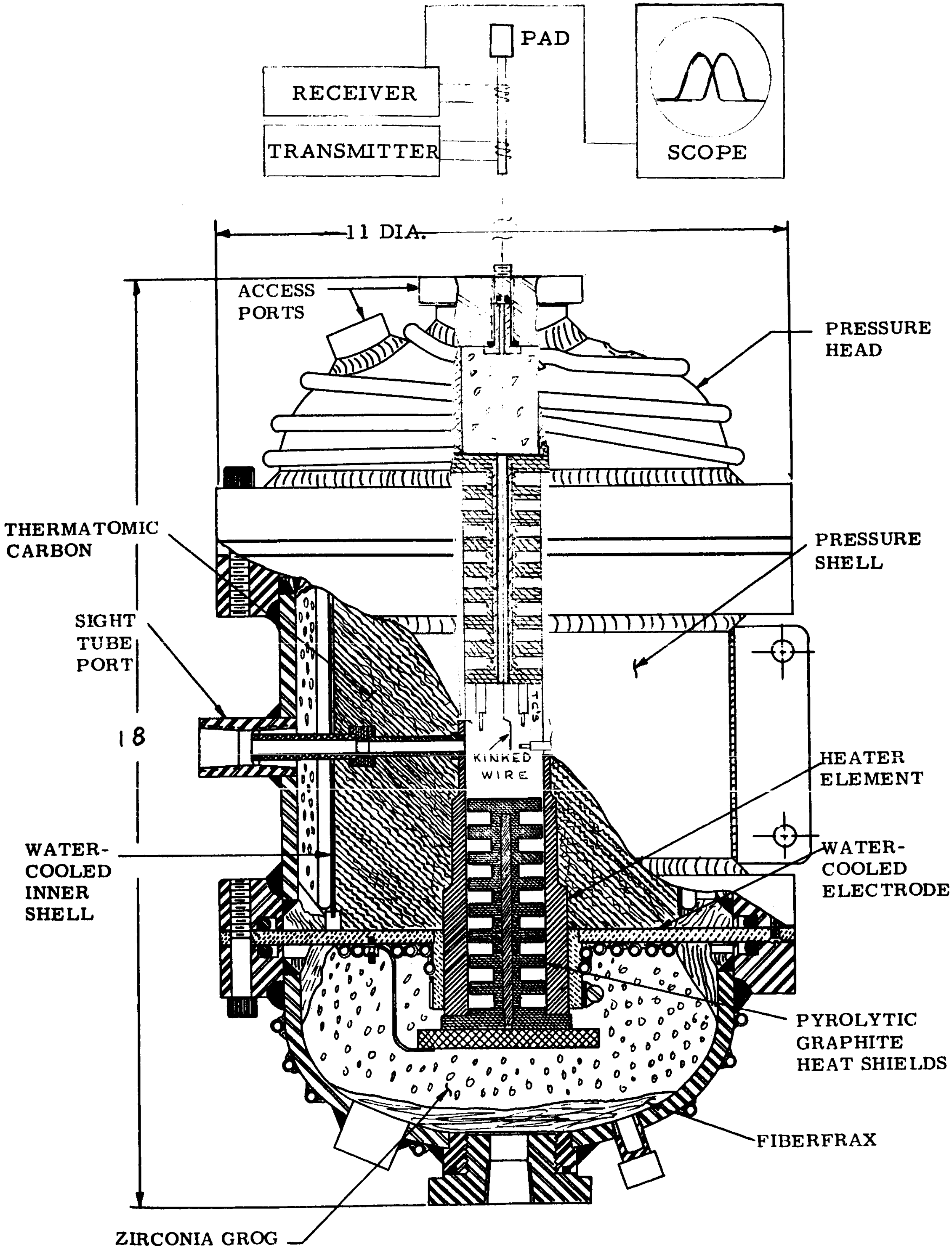

Figure 3. SCHEMATIC OF THE 7000°R RADIANT HEATING SOURCE FOR TESTING AND CALIBRATING THIN WIRE ULTRASONIC THERMOMETER.

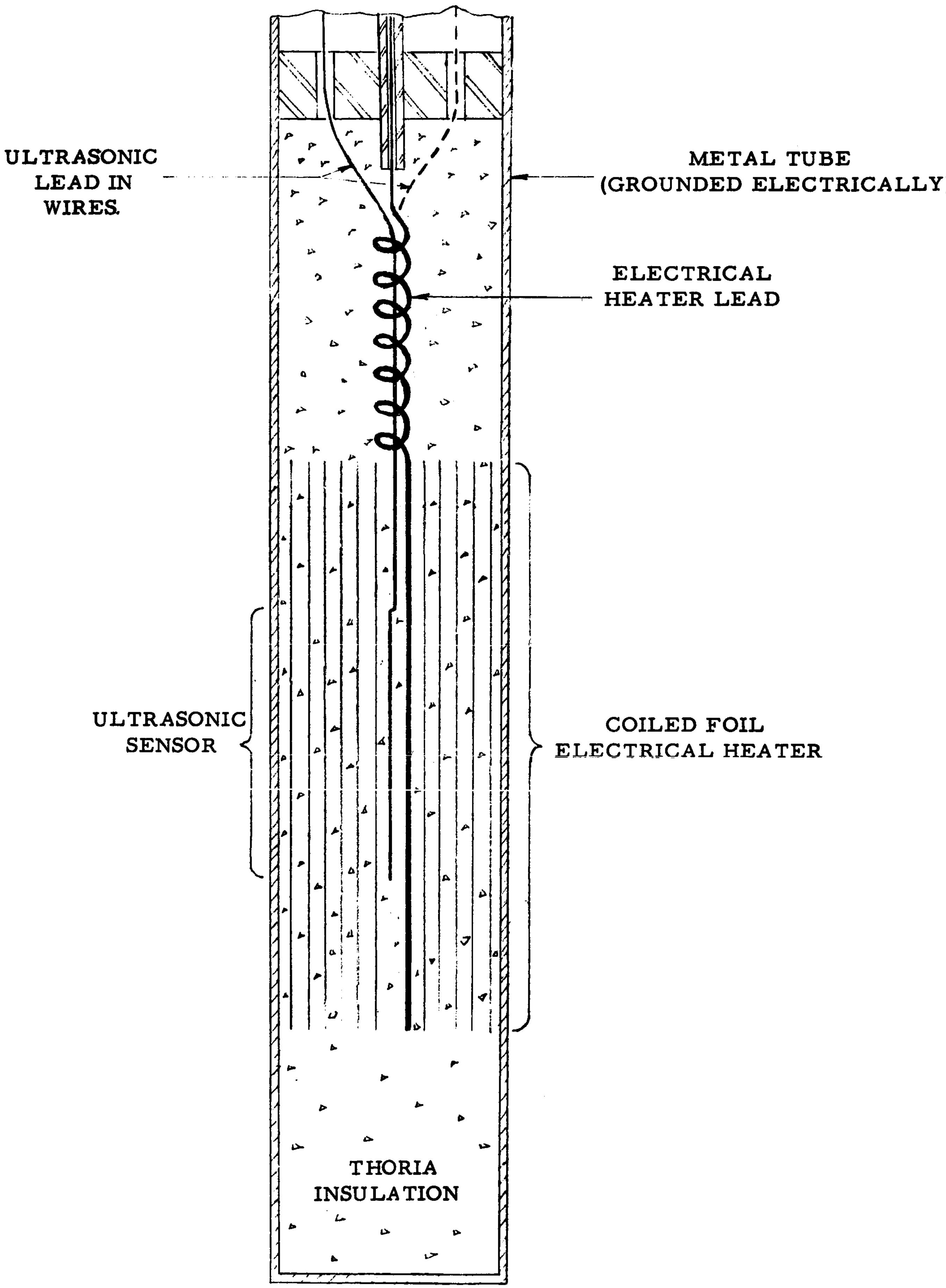

Figure 4. SCHEMATIC OF CAPSULE FOR STUDYING RADIATION EFFECTS AT ELEVATED TEMPERATURES. CAPSULE EMPLOYS COILED FOIL ELECTRICAL HEATER AND THORIA GAMMA HEATER.

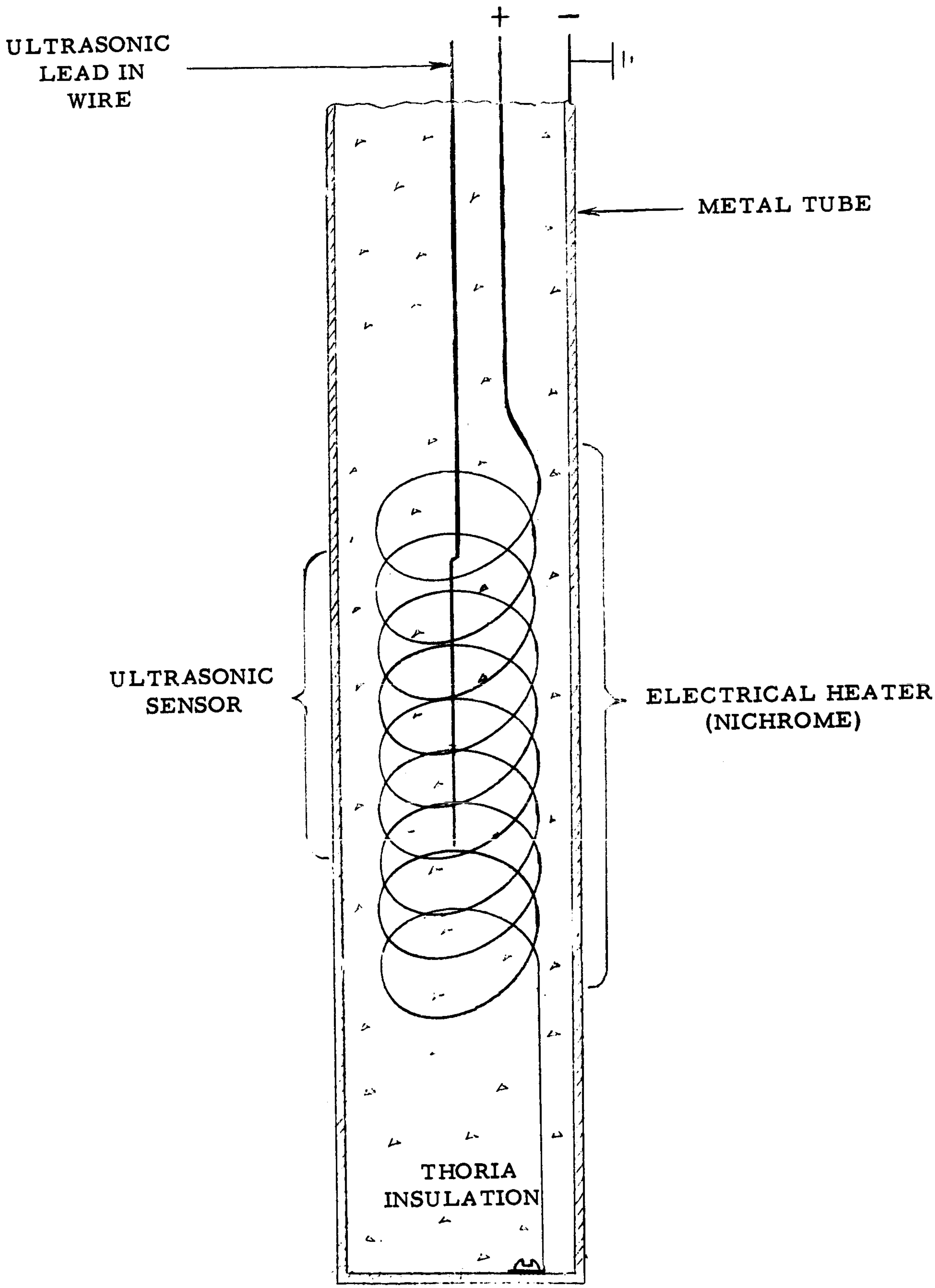

Figure 5. SCHEMATIC OF CAPSULE FOR STUDYING RADIATION EFFECTS AT ELEVATED TEMPERATURES. CENTER OF CAPSULE MAY BE SEVERAL THOUSAND $^{\circ}$R HOTTER THAN ELECTRICAL HEATER, DUE TO GAMMA HEATING.

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